

## The Use of High-Resolution Terrain Data in Gravity Field Prediction

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## ABSTRACT

The aim of this paper is to develop, test and, to some extent, compare different types of gravity prediction methods for local and regional gravity evaluation. Four different test areas have particularly been selected in view of different prediction requirements. Also different parts of the spectrum of the gravity field were considered.

## 1. INTRODUCTION

From modern seismic tomography and other results it is known that lateral density variations have been underestimated in the past. Consequently, gravity variations at the surface of the earth are difficult to predict. On the other hand, modern photogrammetric and altimetric measurements give way to very detailed models of the terrain for estimating gravity in continental areas. Four different areas were selected in order to test various aspects of regional and local gravity modeling. Different mathematical tools have been used in order to test their ability to predict gravity under various conditions.

## 2. DESCRIPTION OF PREDICTION TESTS

Test area one comprises a 500 by 300 km area in Northern Argentina, Southern Bolivia and Northern Chile in the high Andes. Based on a recent terrestrial gravity survey (Goetze et al., 1988) which could be assumed to be free of errors in that comparison a study of the accuracy of Rapp's (1981, 1986) global gravity models was possible in a zone where very scarce surface gravity data was available to the global models. The area is a typical subduction zone and was recently studied in detail by Isacks (1988). This is one of the few areas where the geophysical structure is relatively well known from seismic results even though details of the gravity field are not well known. Nevertheless, the comparison was based on a regular Airy-Heiskanen model using a compensation depth of 40 and 50 km, respectively. The investigation in terms of isostatic anomalies was done in order to reduce the effect of erroneous elevation data and local effects. The two data sets could be assumed to be independent of each other. Basically, wave lengths up to degree  $n = 180$  were considered. The comparison was made in terms of free air, Bouguer and isostatic gravity. The comparison indicates a surprisingly good agreement of large scale phenomena whereas smaller phenomena of the gravity field reveal discrepancies of the order of  $\pm 10$  mgal, as expected.

A second test area is characterized by alpine overthrust, leading to strongly varying anomalous regression of free air gravity with elevation. Therefore, Nettleton type prediction does not lead to good free air or Bouguer gravity estimates as in the case of homogeneous parts of the Northern Alps. The area was chosen in order to demonstrate the difficulties associated with overthrust and similar density variations in mountain areas

which can make local gravity prediction quite erroneous unless precise geological information is available. But there are few areas where detailed density information is available where gravity is unsurveyed. In the area under consideration the density values determined by the Nettleton method differ about 0.1 to 0.2  $\text{gr/cm}^3$  from that determined by geological means. For details see (Kling et al., 1987).

The overwhelming part of the investigation is related to the third area in the Odenwald close to the Rhinegraben where extremely dense (from ten to fifty meter grid spacing) terrain data were available. The area is dominated by paleozoic mountains and deep (4 km) sediments, in the graben zone, and magmatic rocks of different kind leading to quite discontinuous and significant density variations. Fig. 1 shows a small part of the third test area on the eastern Rhinegraben shoulder (Odenwald) where the majority of the prediction tests were carried out. In order to get a meaningful illustration a grid distance of 100 m was chosen instead of 10 to 50 m as was used in the computations themselves. The figure should illustrate the type of topography for which gravity prediction, based on various mathematical techniques, was carried out using high-resolution terrain, sparse density and a few gravity data. As mean gravity values for blocks of a few kilometer side length are of primary interest to geodesy the smoothing or "smearing" effects inherent in least-squares adjustment of terrain models with respect to relatively few gravity data is not too perturbing.

The fourth test area is located off central Italy close to Sardinia island in the Tyrrhennian Sea which is characterized by extremely thin (10 km) lithosphere. Various types of gravity data including altimetric results were available. Mainly terrain, regional density and gravity data were used for prediction based on various types of spectral analysis.

As a relatively dense gravity net was available the application of various mathematical procedures could be tested. Flat twodimensional Fourier methods (FFT) were used to represent local digital terrain models. Freedman's (1982) well known spherical spline techniques were modified in order to solve strictly local prediction and transformation (conversion of gravity into potential etc.) problems. Pellinen's (1964) classical methods by which he solved Molodensky's linear integral equation approach using terrain data was adapted to regionally varying coefficients for the linear regression of free air gravity with elevation. As a great variety of geophysical parameters such as (1) thickness and density variations in the crust, (2) various types of Moho depths, (3) thickness and density variations in the lithosphere, (4) thickness of sediment layers etc. have been derived for Western Europe from seismic and gravity data this information (which is usually not available for gravity prediction in unsurveyed areas) could be fully exploited for our test areas (2) to (4). These parameters clearly reveal variations of totally different wave lengths  $s$  down to  $s < 30$  km. Consequently, by fully exploiting modern digital terrain models errors of  $> 5$  mgal in smooth hill areas occur which do not average out over distances of 10 to 20 km unless geophysical detail information is available. Deviations from standard isostatic and similar models are of non-isotropic and non-random character so that stochastic or similar regression techniques can only be used reliably if trends can be well estimated from existing (scarce) gravity or similar information.

## 3. CONCLUSIONS

This study which focuses on four primary aspects of modern prediction of gravity in unsurveyed or weakly determined areas reveals the efficiency and limitations of gravity prediction using high-resolution terrain models. It also shows the accuracy of global gravity models in (almost) "unsurveyed" areas characterized by strongly varying irregular gravity fields. It demonstrates the consequences of lateral density variations in the crust and lithosphere. By comparing these results with prediction results earlier derived by others or by us it becomes clear that quite favorable prediction results obtained e.g. in the Northern Alps where homogeneous density prevails should be generalized with great care or should better not be generalized at all. The necessity to supplement global gravity models to be deduced from satellite gradiometry for degrees  $n \leq 180$  by other measurements was shown. In spite of the fact that static models prevail in modeling local and regional gravity for harmonics of degrees  $180 \leq n \leq 1800$  the use of strong correlation of free air gravity with terrain is perturbed by a great variety of significant local and regional effects.

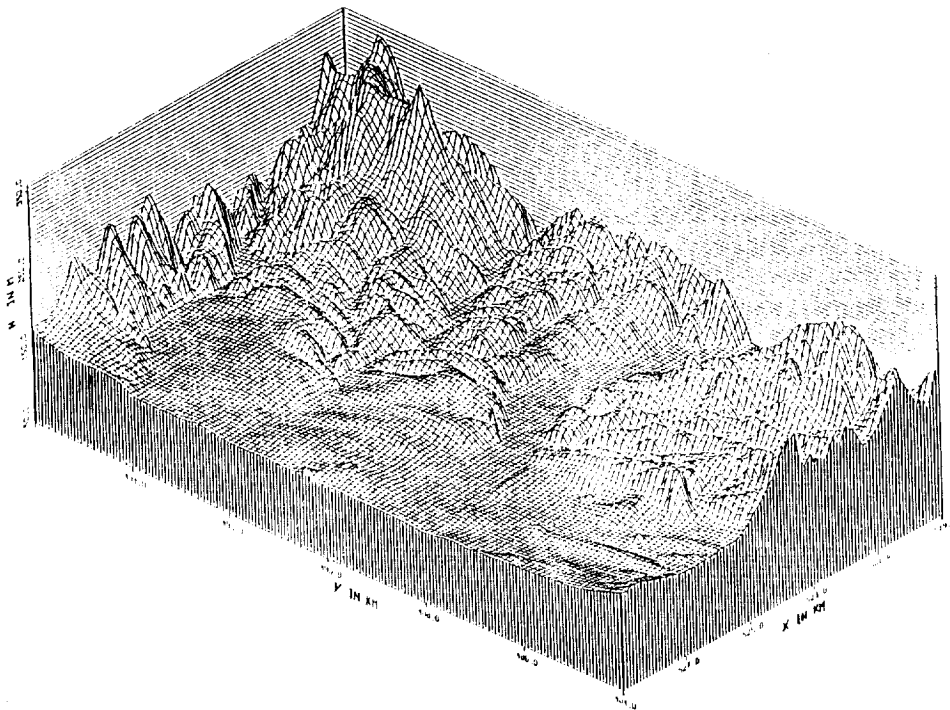


Fig. 1 Typical digital terrain model in third test area

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